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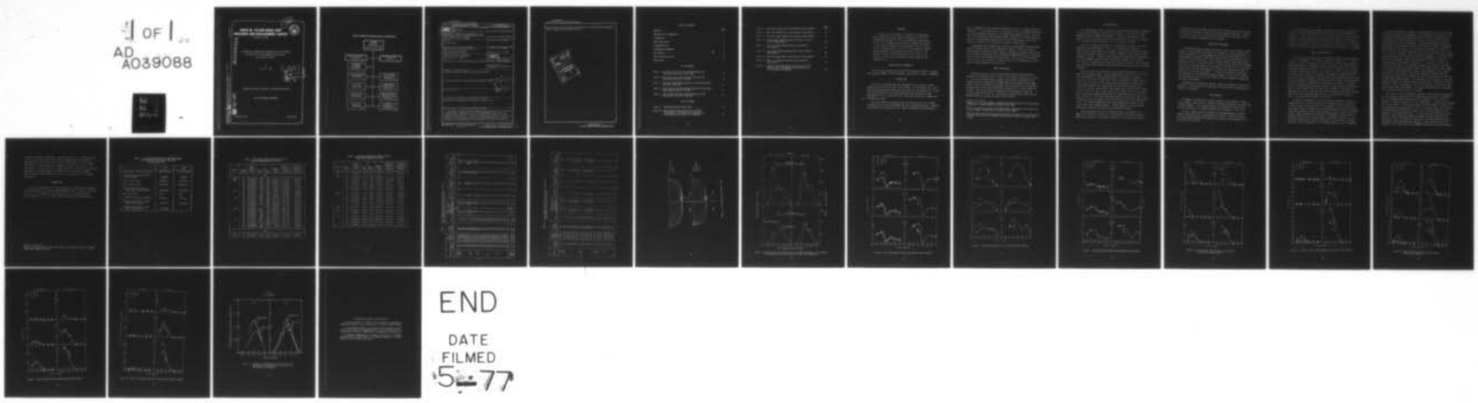

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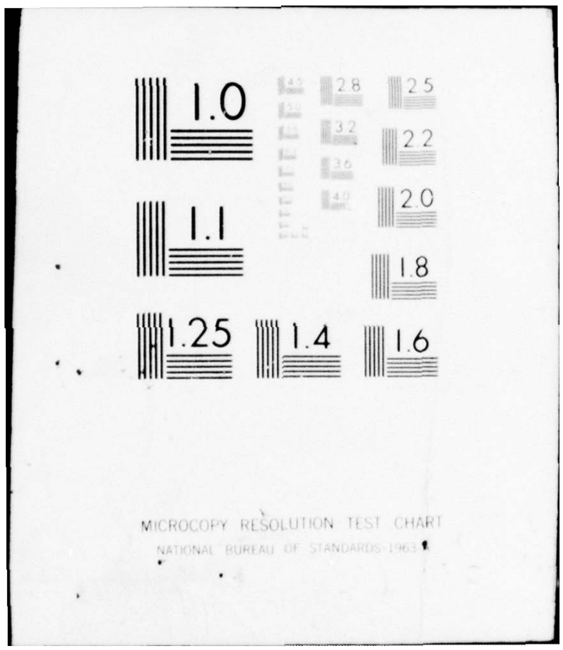
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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

EXPERIMENTAL SEAWORTHINESS COMPARISON OF TWO PROPOSED HULL FORMS OF NUCLEAR-POWERED GUIDED-MISSILE STRIKE CRUISER (CSGN)

by

Harry D. Jones

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SHIP PERFORMANCE DEPARTMENT

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EXPERIMENTAL SEAWORTHINESS COMPARISON OF TWO PROPOSED HULL FORMS OF NUCLEAR-POWERED GUIDED-MISSILE STRIKE CRUISER (CSGN)

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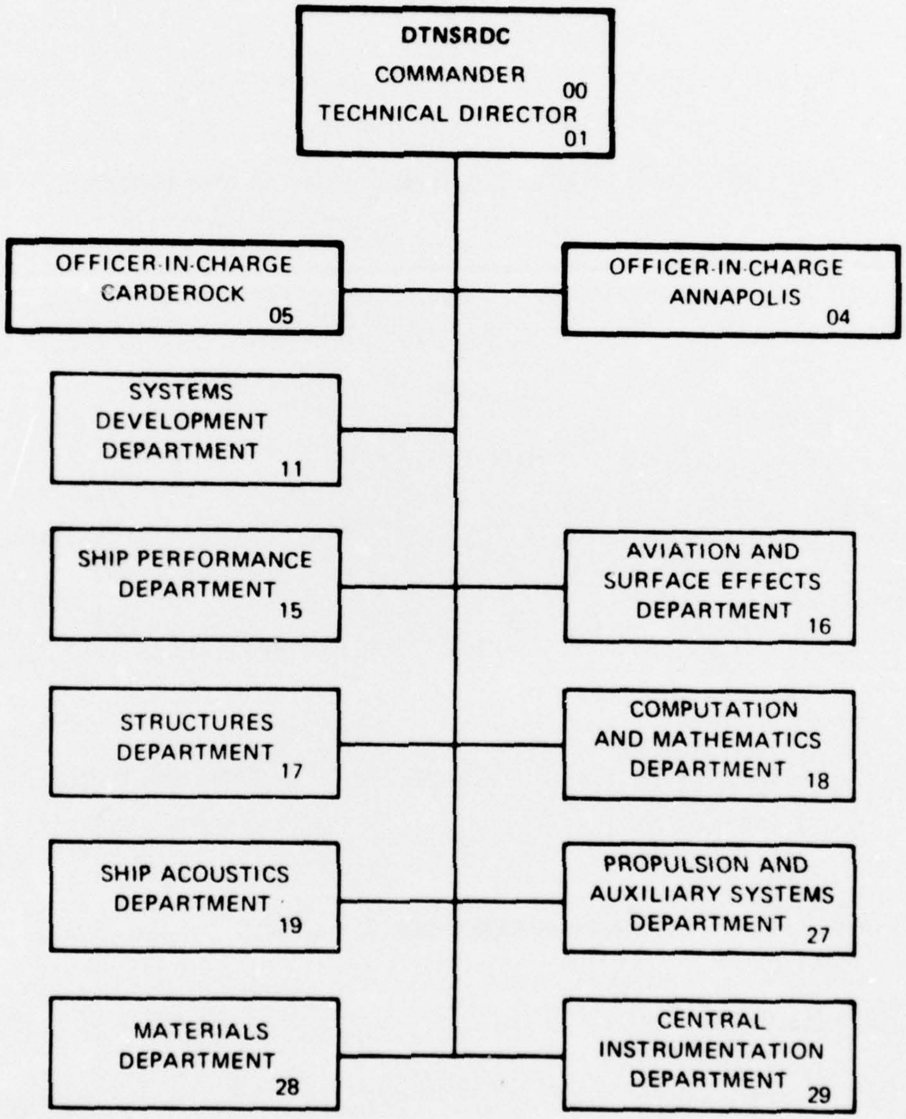

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The David W. Taylor Naval Ship Research and Development Center undertook to experimentally determine which of two proposed hull designs for the nuclear-powered, guided-missile strike cruiser (CSGN) exhibited the best seakeeping characteristics. Extensive seaworthiness experiments were carried out for the large waterplane version with a comprehensive program being conducted for the conventional version as well. The results indicate the next page

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The David W. Taylor Naval Ship Research and Development Center undertook to experimentally determine which of two proposed hull designs for the nuclear-powered, guided-missile strike cruiser (CSGN) exhibited the best seakeeping characteristics. Extensive seaworthiness experiments were carried out for the large waterplane version with a comprehensive program being conducted for the conventional version as well. The results indicate the two versions are similar with the conventional version exhibiting generally better seaworthiness characteristics.

ADMINISTRATIVE INFORMATION

This work was supported by the Naval Ship Engineering Center's funding Work Request WR 66372, dated 10 September 1976 (Work Unit Number 1-1568-867).

INTRODUCTION

Two hull form designs have been proposed for a new class of nuclear-powered, guided-missile strike cruisers (CSGN). The two designs are similar with the most outstanding difference being that one, designated C 24.2 or LWP, has a wide transom stern and large waterplane area, whereas the other, designated C 17.2 or conventional hull, has a more conventional shaped stern and waterplane area.

This experimental investigation was carried out as part of a program to establish a ship motion data base for the two candidate designs. Previous work conducted at the David W. Taylor Naval Ship Research and Development

Center (DTNSRDC) has been reported in References 1 and 2.* The work reported in Reference 1 is a thorough analytical investigation, using the DTNSRDC Ship-Motion and Sea-Load Computer Program, of the seaworthiness characteristics of the two hulls with comparisons of the two being made. Reference 2 is also primarily an analytical investigation comparing the two hull forms; however, this investigation is limited to the roll motion and means of stabilizing it.

The present report presents the results of the experimental seaworthiness program conducted with the two proposed hull designs. The two hulls were experimentally examined at various headings, speeds and irregular long-crested wave conditions to determine their comparative seaworthiness merits with respect to ship motion, keel slamming and deck wetness. The results of this comparison will help provide a basis for selecting which of the candidate hull forms exhibits better seakeeping characteristics.

MODEL PARTICULARS

Ship particulars for both the conventional and the large waterplane versions of the CSGN are given in Table 1 with the body plans shown in Figure 1. The 5.07 metre models were previously constructed at Hydronautics of fiberglass and are designated by DTNSRDC model numbers 9004 (LWP) and 9005 (CONV). Each of the models was equipped with two outward turning propellers. The models were fitted with catch tanks at Station 3.5 to collect water over the bow. The tanks contained 25-gallons-per-minute pumps to remove the collected water during the run. The bows of the models were fitted with the modeled bulwark to simulate the design configuration.

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[1] Motter, L.E. and T.R. Applebee, "Seaworthiness Predictions for Two Preliminary CSGN Designs," DTNSRDC Report SPD-724-01 (Sep 1976).

[2] Foley, E.W. and H.D. Jones, "Roll Stabilization Investigation for the Strike Cruiser (CSGN)," DTNSRDC Report SPD-724-02 (Sep 1976).

*Some additional work concerning the above-water bow design of the conventional hull was also performed at DTNSRDC, but the results were not formally published.

INSTRUMENTATION

The experimental study to determine the seaworthiness characteristics of the two proposed CSGN hull designs was carried out in the Maneuvering and Seakeeping Facility (MASK) at the Center. Throughout the experiments the models were self-propelled with no rigid constraints on the motion responses, i.e., the models were free to move in all six degrees of freedom.

Each of the models was powered by a 5-horsepower d-c motor. The model speed was controlled manually through this motor and was regulated in accordance with the present carriage speed. Sway and yaw signals were used as input to the steering servo units, which corrected the rudder angle and held the model on course. Tethering lines, required for acceleration and deceleration of the model, along with power cables and transducer signal cables, were the only interconnections from the carriage to the model. While data was being recorded, these lines and cables were slack and did not affect the model responses.

Various types of instrumentation and transducers were used in collecting data during the experiments. Angular measurements, such as pitch, roll, and yaw, were measured using gyroscopes mounted in the models. Ultrasonic transducers were used to measure the linear displacements of heave, sway, and surge. Bow and stern vertical velocities were measured with accelerometers. The bow accelerometer was located along the longitudinal centerline at Station 3. The stern accelerometer was located along the longitudinal centerline at Station 15. Keel slamming pressure was measured by a strain gauged wafer type pressure gauge mounted along the longitudinal centerline on the keel at Station 3. The sonar dome window emergences were determined by video coverage of the window location (Station 0.45 at the keel) during the experiments. This video coverage was later analyzed manually to determine the rate of sonar dome window emergences. Video coverage of the bow was also analyzed to determine the rate of deck wetnesses at the bow.

A catch tank was installed in the bow of each of the models with its opening from Station 3 to Station 3.5 longitudinally and from deck edge to deck edge transversely. A vertical, forward curving shield was installed

coincident with the aft edge of the catch tank to deflect water into the tank. The tank also contained a 25-gallon per minute (model scale) pump to remove the water during the run so as to minimize the effect of the water in the tank on the dynamic characteristics of the model.

EXPERIMENTAL PROCEDURE

The CSGN experimental program consisted of runs in long-crested irregular waves at various headings and speeds for the models of the two proposed hull designs considered. The large waterplane version was investigated first. It was examined at headings of 150 (210), 120, 60, 30 and zero degrees for ship speeds of 10, 20, and 25 knots in long-crested irregular waves approximating Sea States 6 and 7. Due to difficulty in controlling the model at 120 degrees, data for the two lower speeds at this heading in Sea State 7 are not presented. An additional condition was examined for a heading of 180 degrees (head) in Sea State 7 at 20 knots ship speed. A similar investigation of conditions was attempted for the conventional design; however, similar control problems at 120 degrees as well as time restrictions limited the number of speeds and sea states investigated.

Representative experimental spectral shapes are presented in Figure 2 for headings in which they were utilized along with theoretical Pierson-Moskowitz spectra for reference.

DATA ANALYSIS

Throughout the experiments the model responses were recorded in analog form on magnetic tape as well as being digitized and recorded by the on-carriage Interdata computer. This digital data was later grouped by condition and spectrum analyzed by an Interdata computer for presentation in this report.

The keel slamming data was recorded during experimentation on analog magnetic tape as well as on oscillograph strip charts. These strip charts were later analyzed manually to determine the magnitude and frequency of the keel slams which occurred.

The deck wetness and sonar dome window emergence data were recorded by means of video coverage of the bow of the models during the experimental investigation. These video records were then analyzed manually to determine the frequency of occurrence of deck wetnesses and sonar dome window emergences. To determine the catch tank results, the water was pumped from the tank during a data run and measured. These measured totals were combined for a condition to determine the rate of water into the catch tank as presented in this report.

RESULTS AND DISCUSSION

The results of this experimental investigation compare the two proposed versions of the CSGN hull form and are presented in tabular form in Tables 2 through 5, as well as being plotted as a function of relative wave heading in Figures 3 through 10. Presented in Tables 2 and 3 are the root mean square single amplitude motion results, i.e., pitch, roll, heave, vertical velocity at Station 3, and vertical velocity at Station 15, for the large waterplane and conventional versions of the CSGN for the headings, speeds, and significant wave height investigated. The keel slamming and deck wetness results are similarly presented in Tables 4 and 5 along with the number of wave encounters and time for each of the conditions investigated. The results in Tables 4 and 5 are presented as the average and maximum impact pressure on the keel at Station 3, the number of keel slams per hour at Station 3, the number of emergences per hour for the sonar dome window located at Station 0.45 and the keel, the number of deck wetnesses per hour at the bow and the amount of water in the catch tank at Station 3.5 per hour.

The graphic representation of the results are presented in Figures 3 through 10 as a function of the heading of the model relative to the long-crested irregular Sea States 6 and 7 investigated at 10, 20, and 25 knots ship speed. Figure 3 presents the root mean square pitch results indicating that the conventional version exhibits generally less pitch motion with the largest values encountered at a heading of 120 degrees for each version in Sea State 6 and for the large waterplane in Sea State 7; however, the conventional version seems to peak at 150 degrees in a Sea State 7, although the data is more limited here. The root mean square roll results presented

in Figure 4 again generally indicate the conventional hull form as exhibiting less motion than the large waterplane. Also indicated in this figure is that for the large waterplane with GM2 slightly more RMS roll is experienced in a Sea State 6 at 10 knots than for GM1; while in a Sea State 7 at 25 knots considerably less roll is encountered. It should be pointed out that due to the difficulty encountered in obtaining the Sea State 7, 25-knot, 120-degree heading condition the results in this case may be misleading. Presented in Figure 5 are the root mean square heave motion results indicating the similarities of the two proposed hull forms with respect to heave. The average impact pressures measured on the keel at Station 3 are presented in Figure 6 for the conditions investigated. Again, the conventional hull form is generally indicated as having preferable characteristics. Presented in Figure 7 are the experimental results for the number of keel slams at Station 3 per hour with the conventional version again generally indicating lower values; however, in this case it does experience a slightly higher slamming rate for some of the conditions investigated. The results presented in Figure 8 generally indicate a preference for the conventional hull form with respect to the rate of sonar dome window emergences. The deck wetness rate presented in Figure 9 generally indicate the two hull forms as being similar. Again, the similarity of the hull forms is indicated in Figure 10 with respect to the rate of water flow into the catch tank; however, in this case some preference is indicated for the large waterplane version of the CSGN.

The results of this investigation generally indicate that the conventional hull form would be preferable to the large waterplane version of the CSGN as far as the seaworthiness characteristics are concerned. This conclusion, however, is slightly different from that in Reference 1, especially with respect to the pitch motion. In an effort to explain this difference, a comparison of the response amplitude operators for the pitch motion was made, with a representative case being presented in Figure 11 for a relative heading of 120 degrees at a ship speed of 20 knots. It may be seen here that while the conventional version shows good comparison between the experimental and the analytical results, the analytical results for the large waterplane version underpredict those determined experimentally. Other conditions were also compared with the predictions of the DTNSRDC Ship-Motion and Sea-Load Computer

Program as presented in Reference 1 with the same results. In head waves the results were also compared with YF 17[3] which showed good comparison with experimental results for both versions of the CSGN; however, the pitch RAO's from Reference 1 exhibited similar comparisons to those in Figure 11. The differences in the two analytical procedures may be attributed to the so-called end effects as they have been incorporated in the six-degree-of-freedom computer program used in Reference 1 but are not present in YF 17, the head seas program.

CONCLUSIONS

The results presented herein give a comprehensive comparison of seaworthiness characteristics of the two proposed CSGN hull forms. The results indicate similarity in the responses of the two hull forms, with the conventional version generally indicating slightly better seaworthiness characteristics.

[3] Frank, W. and N. Salvesen, "The Frank Close-Fit Ship-Motion Computer Program," NSRDC Report 3289 (June 1970).

TABLE 1 - SHIP PARTICULARS FOR THE LARGE WATERPLANE AND CONVENTIONAL VERSIONS OF THE CSGN
(Scale Ratio = 40)

	LWP	CONV
Displacement, Tonnes (Long Tons)	19,541(19,232)	19,541(19,232)
Length between Perpendiculars, Metres (Feet)	203(666)	203(666)
Draft, Metres (Feet)	6.86(22.5)	6.75(22.1)
Beam, Metres (Feet)	22.74(74.6)	23.28(76.4)
Vertical Center of Gravity (above keel), Metres (Feet)	8.60(28.2)	8.53(28.0)
Block Coefficient	0.53	0.53
Longitudinal Radius of Gyration	0.25 L_{pp}	0.25 L_{pp}
Transverse Metacentric Height (GM1), Metres (Feet)	3.47(11.4)	2.24(7.35)
Transverse Metacentric Height (GM2), Metres (Feet)	2.71(8.89)	--

TABLE 2 - ROOT MEAN SQUARE MOTION RESULTS FOR THE LARGE WATERPLANE VERSION OF THE CSGN

Heading	Speed (knots)	Wave Height (metres, feet)	Pitch (deg)	Roll (deg)	Heave (metres, feet)	Vertical Velocity at Station 3 (MPS, FPS)	Vertical Velocity at Station 15 (MPS, FPS)
				GM1			
180°	20	9.2,30.2	1.76	0.72	1.5,5.1	4.7,15.4	0.9,2.8
150°	10	5.3,17.5	0.95	1.87	0.7,2.2	2.1, 6.7	0.4,1.3
	20	5.7,18.6	1.04	2.02	0.8,2.6	2.9, 9.6	0.5,1.5
	25	5.7,18.8	0.97	2.41	0.8,2.8	3.0,10.0	0.5,1.6
	10	10.0,32.9	1.78	2.81	1.5,5.0	3.8,12.5	0.9,2.9
	20	10.1,33.0	2.02	2.78	1.8,5.7	5.4,17.6	1.0,3.3
	25	10.2,33.5	1.99	2.69	1.9,6.3	5.9,19.5	1.1,3.5
120°	10	5.2,17.1	1.79	4.12	0.9,2.8	3.3,10.9	0.6,2.0
	20	5.0,16.4	1.37	3.25	1.1,3.6	4.0,13.2	0.8,2.5
	25	5.2,17.1	1.20	3.28	1.3,4.1	4.4,14.3	0.9,2.9
	25	8.7,28.6	2.28	4.24	2.0,6.5	5.4,17.8	1.2,4.0
60°	10	4.4,14.4	0.76	3.55	0.7,2.2	1.3, 4.2	0.4,1.4
	20	4.3,14.2	0.64	1.82	0.5,1.8	0.9, 2.9	0.3,1.0
	25	5.1,16.6	0.73	1.87	0.6,1.9	0.9, 2.9	0.3,0.9
	10	6.8,22.3	1.04	4.55	1.0,3.3	1.7, 5.6	0.6,2.0
	20	6.4,20.9	0.87	2.01	0.8,2.6	1.2, 4.0	0.5,1.5
	25	6.7,22.1		2.03	0.6,2.0	0.9, 3.0	0.4,1.2
30°	10	5.5,18.0	0.72	1.33	0.6,1.8	1.0, 3.2	0.3,1.0
	20	6.0,19.8	0.67	1.08	0.6,1.9	0.8, 2.5	0.2,0.8
	25	5.4,17.6	0.52	2.10	0.5,1.6	0.9, 2.9	0.1,0.5
	10	10.6,34.9	1.23	1.87	1.3,4.2	1.5, 5.0	0.6,1.8
	20	9.2,30.3	1.08	1.81	1.3,3.4	1.0, 3.3	0.4,1.3
	25	7.3,23.8	0.96	3.01	1.2,4.1	0.9, 2.8	0.3,1.1
0°	10	4.9,16.2	0.60	0.48	0.5,1.5	0.7, 2.2	0.2,0.7
	20	5.3,17.5	0.47	0.36	0.4,1.3	0.4, 1.4	0.1,0.4
	25	5.1,16.7	0.49	0.58	0.4,1.2	0.3, 1.1	0.1,0.3
	10	9.1,29.8	1.23	0.60	1.2,3.9	1.4, 4.4	0.5,1.5
	20	9.4,30.9	0.91	0.71	1.1,3.4	0.8, 2.7	0.3,0.9
	25	9.0,29.6	0.86	0.80	1.0,3.2	0.7, 2.3	0.2,0.8
				GM2			
120°	25	8.1,26.4	1.42	2.22	1.2,3.9	4.4,14.5	0.9.2.9
60°	10	5.7,18.7	0.64	4.07	0.5,1.6	1.2, 3.8	0.4,1.2

TABLE 3 - ROOT MEAN SQUARE MOTION RESULTS FOR THE CONVENTIONAL VERSION OF THE CSGN

Heading	Speed (knots)	Wave Height (metres feet)	Pitch (deg)	Roll (deg)	Heave (metres, feet)	Vertical Velocity at Station 3 (MPS, FPS)	Vertical Velocity at Station 15 (MPS, FPS)
180°	20	8.8,29.0	1.83	0.53	1.9,6.3	4.6,15.0	0.9,2.9
150°	10	5.6,18.3	0.91	1.80	0.7,2.2	2.1, 7.0	0.4,1.3
	20	5.6,18.2	1.01	1.30	0.8,2.5	3.0, 9.8	0.5,1.5
	25	5.6,18.3	1.02	1.15	0.9,2.8	3.3,10.7	0.5,1.7
	10	9.6,31.4	1.69	2.56	1.7,5.5	3.7,12.1	0.8,2.7
	20	9.7,31.9	2.15	2.00	1.7,5.7	5.3,17.4	1.0,3.2
	25	10.5,34.3	1.98	2.65	1.9,6.3	5.9,19.3	1.0,3.3
120°	10	5.3,17.5	1.19	2.02	0.8,2.6	3.2,10.5	0.6,2.0
	20	5.1,16.7	1.19	1.85	1.1,3.4	4.0,13.0	0.9,2.8
	25	5.6,18.3	1.30	2.00	1.3,4.2	4.7,15.3	1.1,3.4
	20	6.7,22.1	1.39	2.33	1.2,4.0	4.3,14.2	1.0,3.2
	25	7.1,23.3	1.50	2.79	1.5,5.0	5.2,16.9	1.1,3.6
60°	10	4.4,14.3	0.66	1.94	0.5,1.6	0.9, 3.0	0.3,1.0
30°	10	5.9,19.3	0.64	1.26	0.6,1.9	0.9, 2.9	0.3,1.0
	20	4.9,16.2	0.51	2.43	0.5,1.5	0.5, 1.6	0.2,0.7
0°	10	5.3,17.5	0.63	0.32	0.6,1.9	0.7, 2.4	0.2,0.8
	20	6.2,20.3	0.40	0.82	0.4,1.3	0.4, 1.3	0.1,0.4
	25	4.3,14.0	0.40	1.51	0.4,1.1	0.3, 1.0	0.1,0.3
	10	8.6,28.1	1.18	0.60	1.1,3.7	1.4, 4.4	0.5,1.5

TABLE 4 - KEEL SLAMMING AND DECK WETNESS RESULTS FOR THE LARGE WATERPLANE VERSION OF THE CSGN

Heading	Speed (knots)	Wave Height (metres, feet)	Number of Wave Encounters	Time (hours)	Impact Pressure (Station 3) (Atmospheres)		Keel Slams per hour (Station 3)	Dome Window Emergences per hour	Deck Wetnesses per hour	Water in Catch Tank (% Δ per hour)
					Average	Maximum				
GM1										
180°	20	9.2,30.2	509	1.1	3.18	7.87	4	65	163	51.6
150°	10	5.3,17.5	306	0.7	1.59	1.59	2	7	7	0.2
	20	5.7,18.6	322	0.5	0.73	0.73	2	7	41	1.2
	25	5.7,18.8	319	0.5	0	0	0	2	56	1.1
	10	10.0,32.9	502	1.3	1.29	2.10	3	68	48	29.2
	20	10.1,33.0	457	1.1	1.70	4.80	50	60	173	127.2
	25	10.2,33.5	470	1.0	1.95	7.06	79	54	264	229.2
120°	10	5.2,17.1	326	0.8	0.92	0.92	1	28	13	0
	20	5.0,16.4	510	1.1	0	0	0	14	38	0.2
	25	5.2,17.1	502	1.0	1.12	1.67	5	17	88	0.4
	25	8.7,28.6	268	0.9	1.65	4.91	54	54	137	132.9
60°	10	4.4,14.4	243	0.8	0	0	0	0	0	0
	20	4.3,14.2	152	0.5	0	0	0	0	0	0
	25	5.1,16.6	127	0.7	0	0	0	0	0	0
	10	6.8,22.3	143	0.4	0	0	0	0	0	0
	20	6.4,20.9	127	0.6	0	0	0	0	0	0
	25	6.7,22.1	87	0.4	0	0	0	0	0	0
30°	10	5.5,18.0	130	0.6	0	0	0	0	0	0
	20	6.0,19.8	62	0.6	0	0	0	0	0	0
	25	5.4,17.6	75	0.9	0	0	0	0	0	0
	10	10.6,34.9	127	0.8	0	0	0	0	0	0
	20	9.2,30.3	90	0.8	0	0	0	0	0	0
	25	7.3,23.8	47	0.7	0	0	0	0	0	0
0°	10	4.9,16.2	193	0.9	0	0	0	0	0	0
	20	5.3,17.5	90	0.8	0	0	0	0	0	0
	25	5.1,16.7	44	0.6	0	0	0	0	0	0
	10	9.1,29.8	140	0.6	0	0	0	0	0	0
	20	9.4,30.9	57	0.5	0	0	0	0	0	0
	25	9.0,29.6	48	0.5	0	0	0	0	0	0
GM2										
120°	25	8.1,26.4	284	0.5	1.26	2.32	47	37	191	132.7
60°	10	5.7,18.7	202	0.6	0	0	0	0	0	0

TABLE 5 - KEEL SLAMMING AND DECK WETNESS RESULTS FOR THE CONVENTIONAL VERSION OF THE CSGN

Heading	Speed (knots)	Wave Height (metres, feet)	Number of Wave Encounters	Time (hours)	Impact Pressure (Station 3) (Atmospheres)		Keel Slams per hour (Station 3)	Dome Window Emergences per hour	Deck Wetnesses per hour	Water in Catch Tank (% Δ per hour)
					Average	Maximum				
180°	20	8.8,29.0	506	1.0	1.06	2.76	9	21	116	51.5
150°	10	5.6,18.3	322	0.7	1.79	1.79	2	2	6	0
	20	5.6,18.2	342	0.6	0	0	0	2	19	2.4
	25	5.6,18.3	506	0.9	0.64	1.09	4	1	56	1.9
	10	9.6,31.4	457	1.1	0.59	1.03	8	37	48	37.7
	20	9.7,31.9	464	1.0	1.34	3.60	27	27	175	171.2
	25	10.5,34.3	464	0.8	1.20	2.76	48	33	265	325.8
120°	10	5.3,17.5	274	0.6	0	0	0	13	0	0
	20	5.1,16.7	296	0.6	0	0	0	0	48	6.3
	25	5.6,18.3	306	0.6	0.78	1.54	15	2	118	17.3
	20	6.7,22.1	598	1.2	0.92	1.54	22	26	110	88.1
	25	7.1,23.3	509	0.8	1.48	4.10	29	29	214	131.6
60°	10	4.4,14.3	80	0.4	0	0	0	0	0	0
30°	10	5.9,19.3	153	0.6	0	0	0	0	0	0
	20	4.9,16.2	65	0.5	0	0	0	0	0	0
0°	10	5.3,17.5	168	0.8	0	0	0	0	0	0
	20	6.2,20.3	49	0.5	0	0	0	0	0	0
	25	4.3,14.0	47	0.6	0	0	0	0	0	0
	10	8.6,28.1	124	0.6	0	0	0	0	0	0

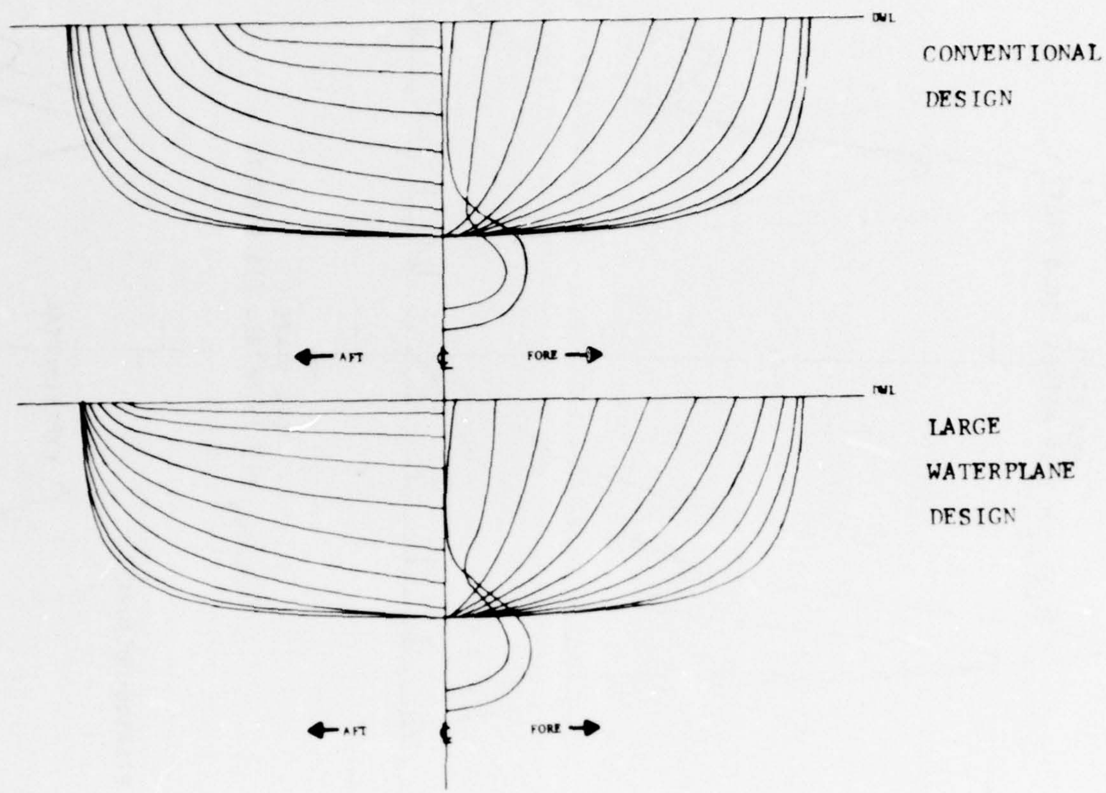

Figure 1 - CSGN Candidate Hull Body Plans

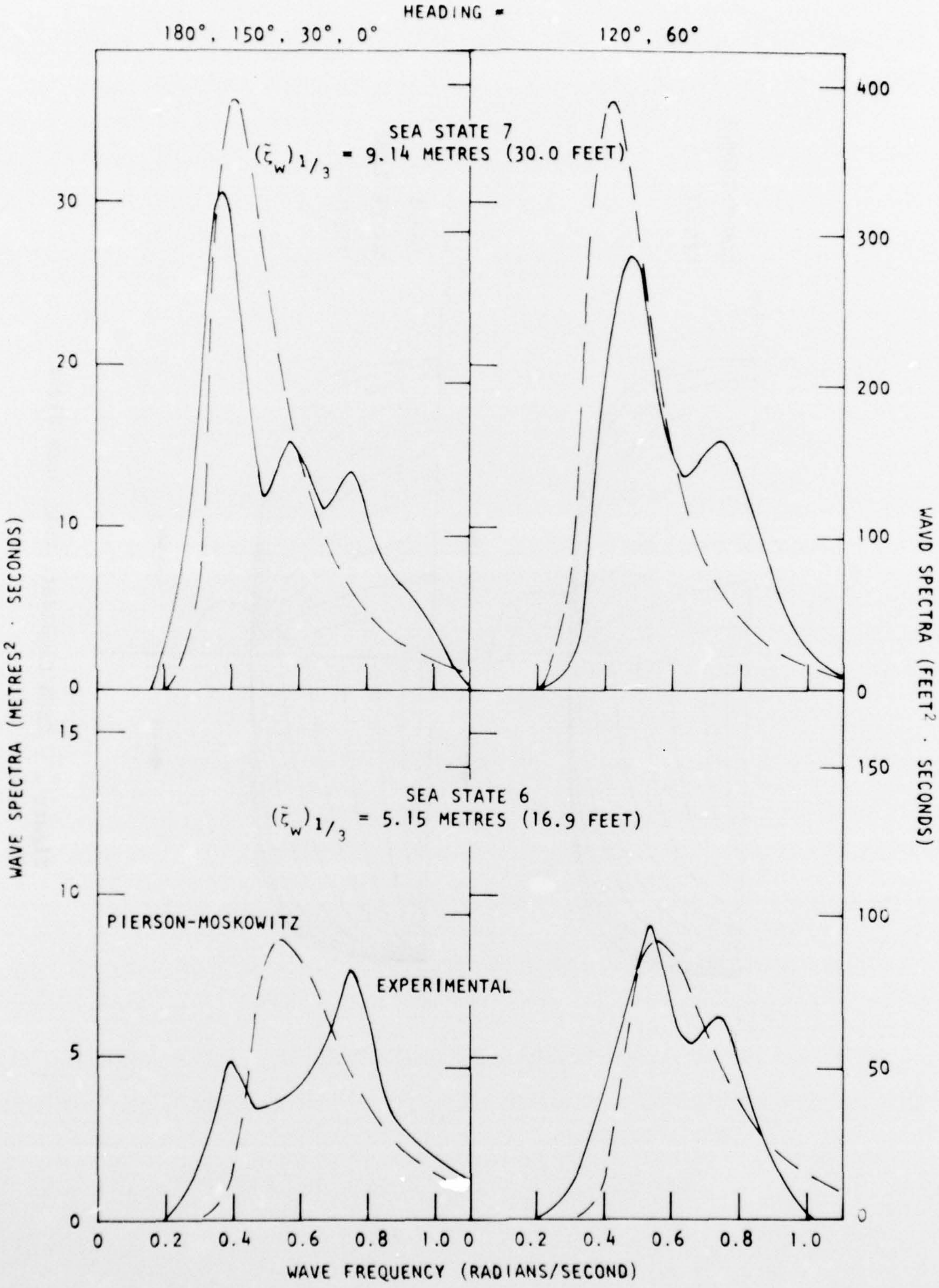

Figure 2 - Representative Wave Spectra for the CSGN Experimental Investigation with Theoretical Pierson-Moskowitz Spectra for Comparison

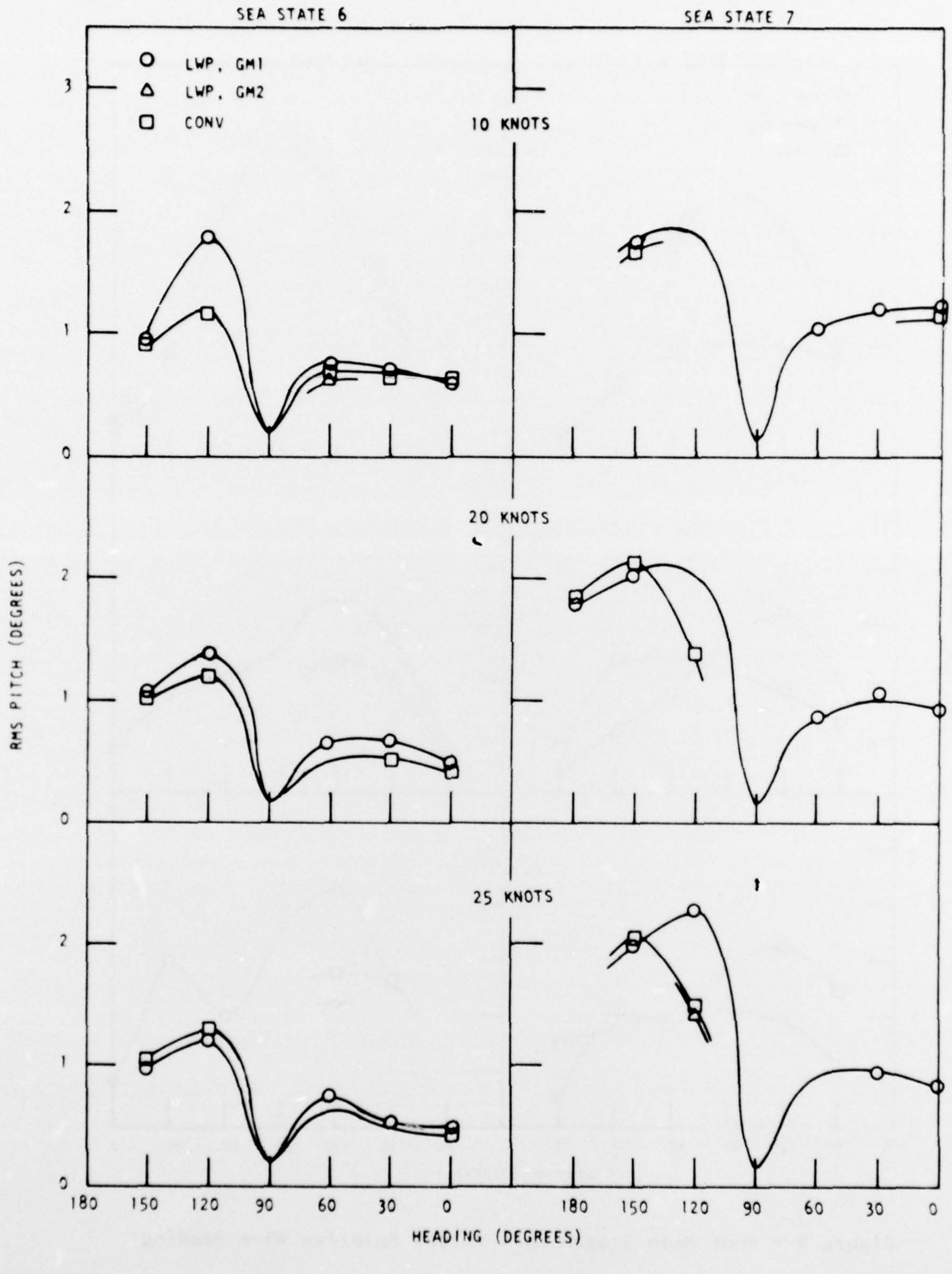

Figure 3 - Root Mean Square Pitch versus Relative Wave Heading

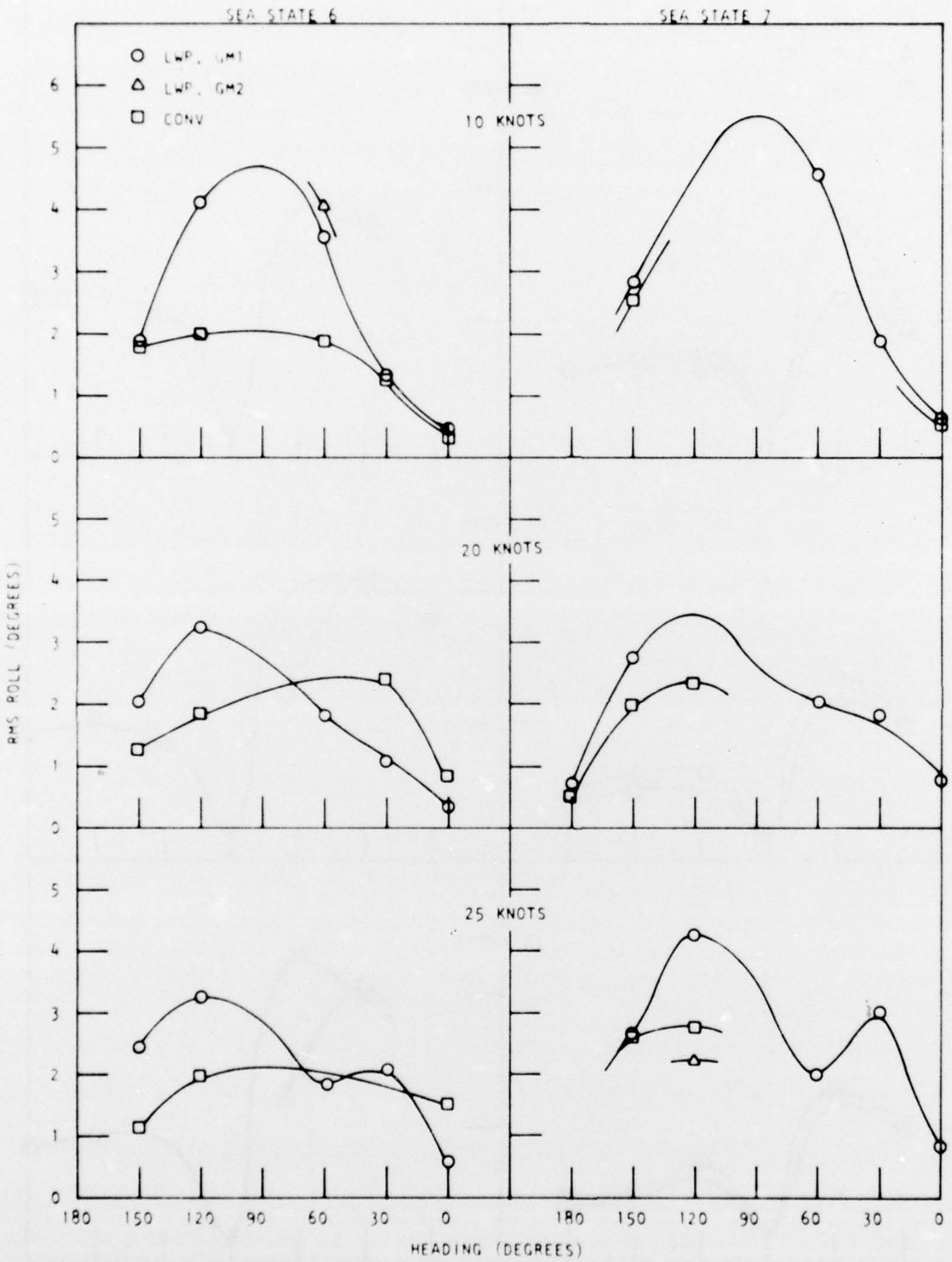

Figure 4 - Root Mean Square Roll versus Relative Wave Heading

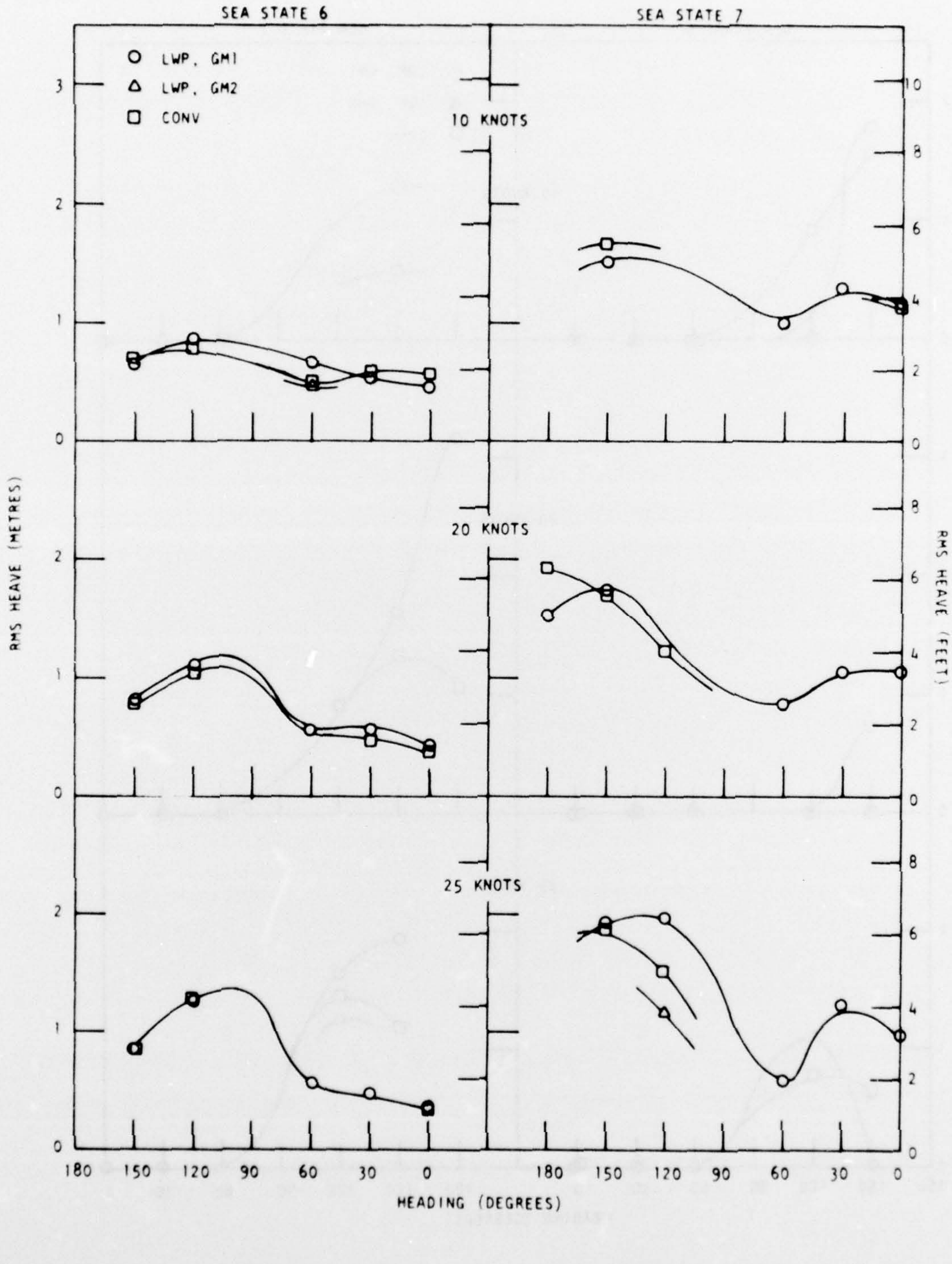

Figure 5 - Root Mean Square Heave versus Relative Wave Heading

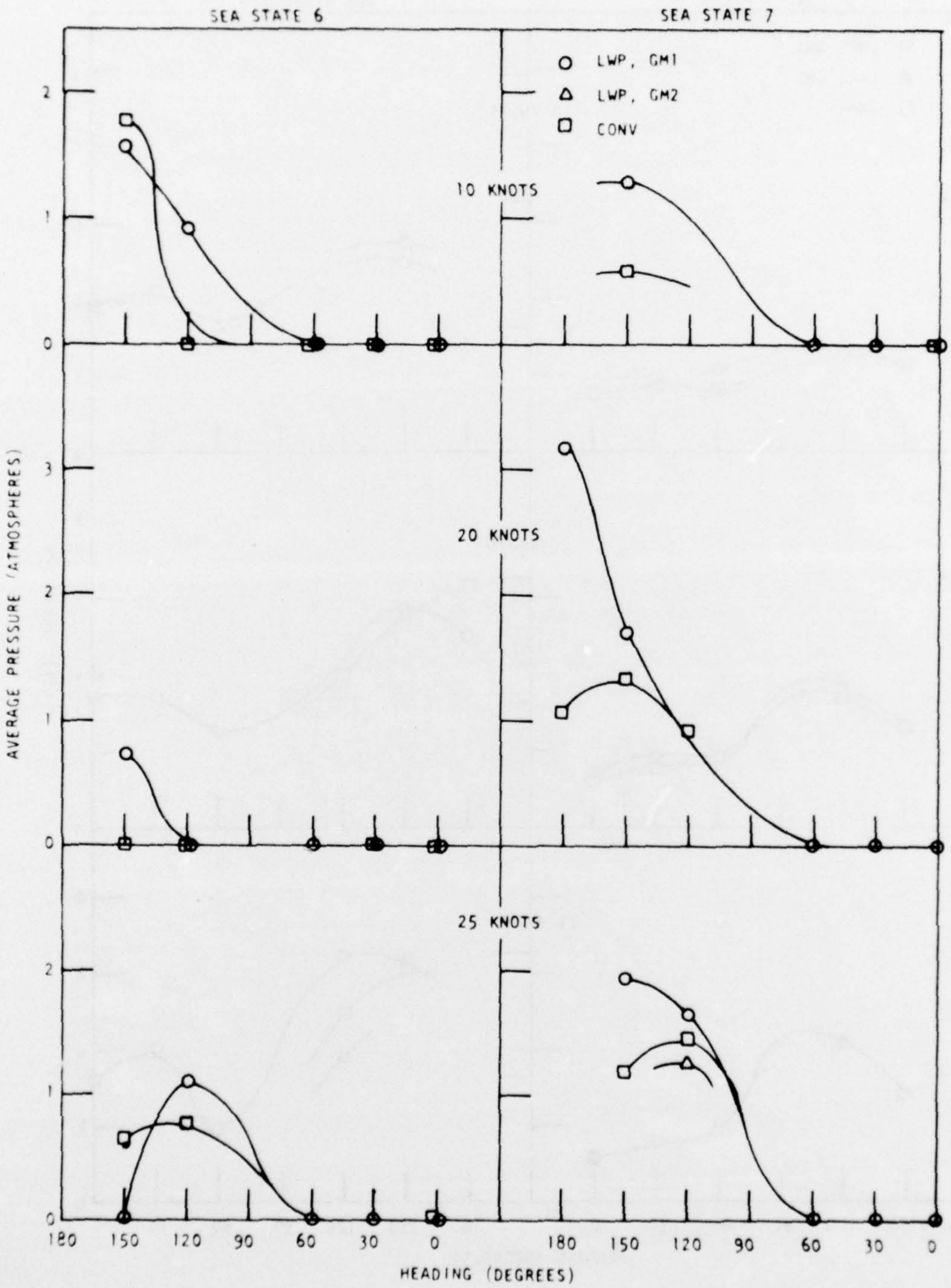

Figure 6 - Average Keel Impact Pressure at Station 3 versus Relative Wave Heading

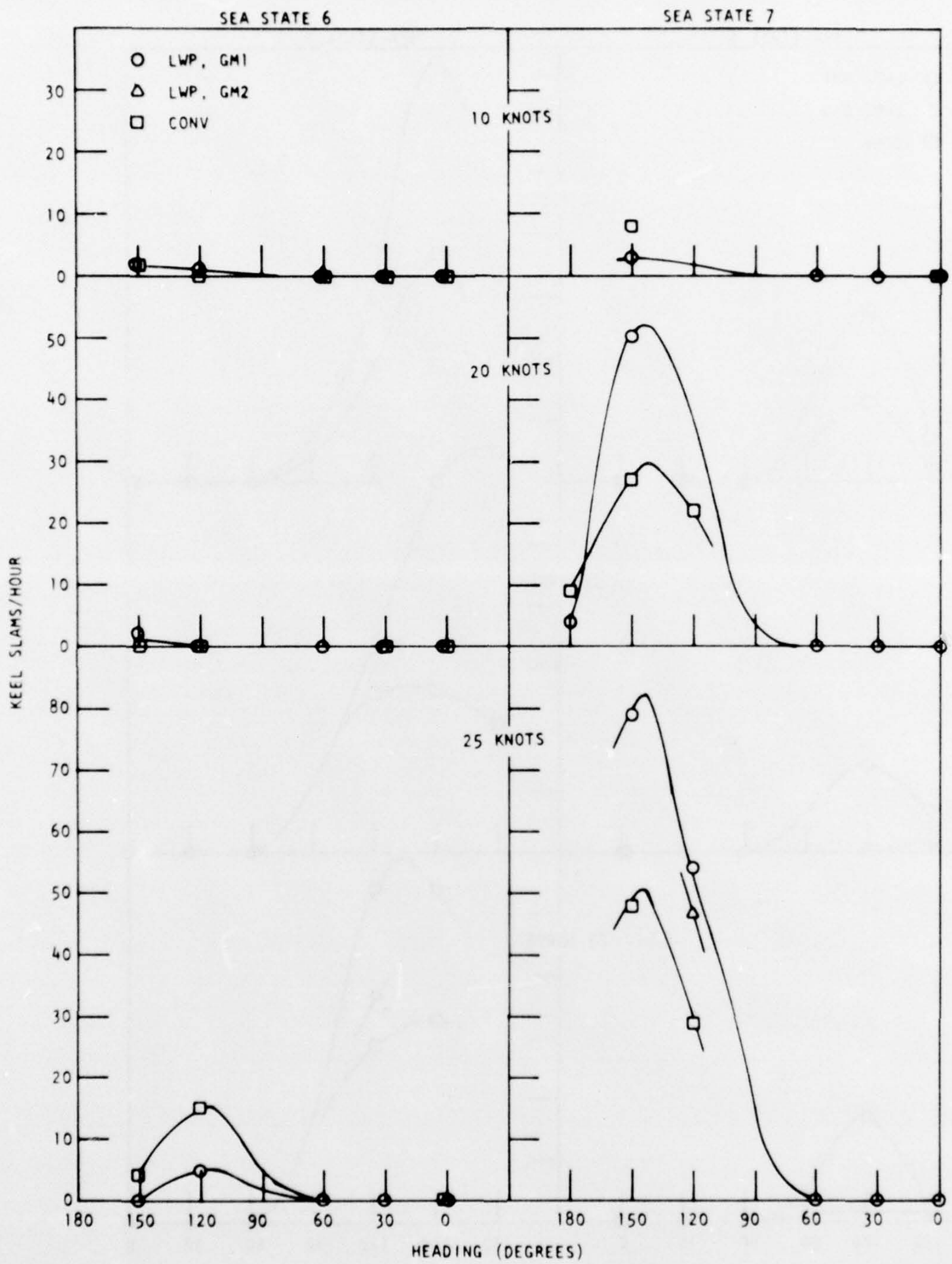

Figure 7 - Station 3 Keel Slamming Rate versus Relative Wave Heading

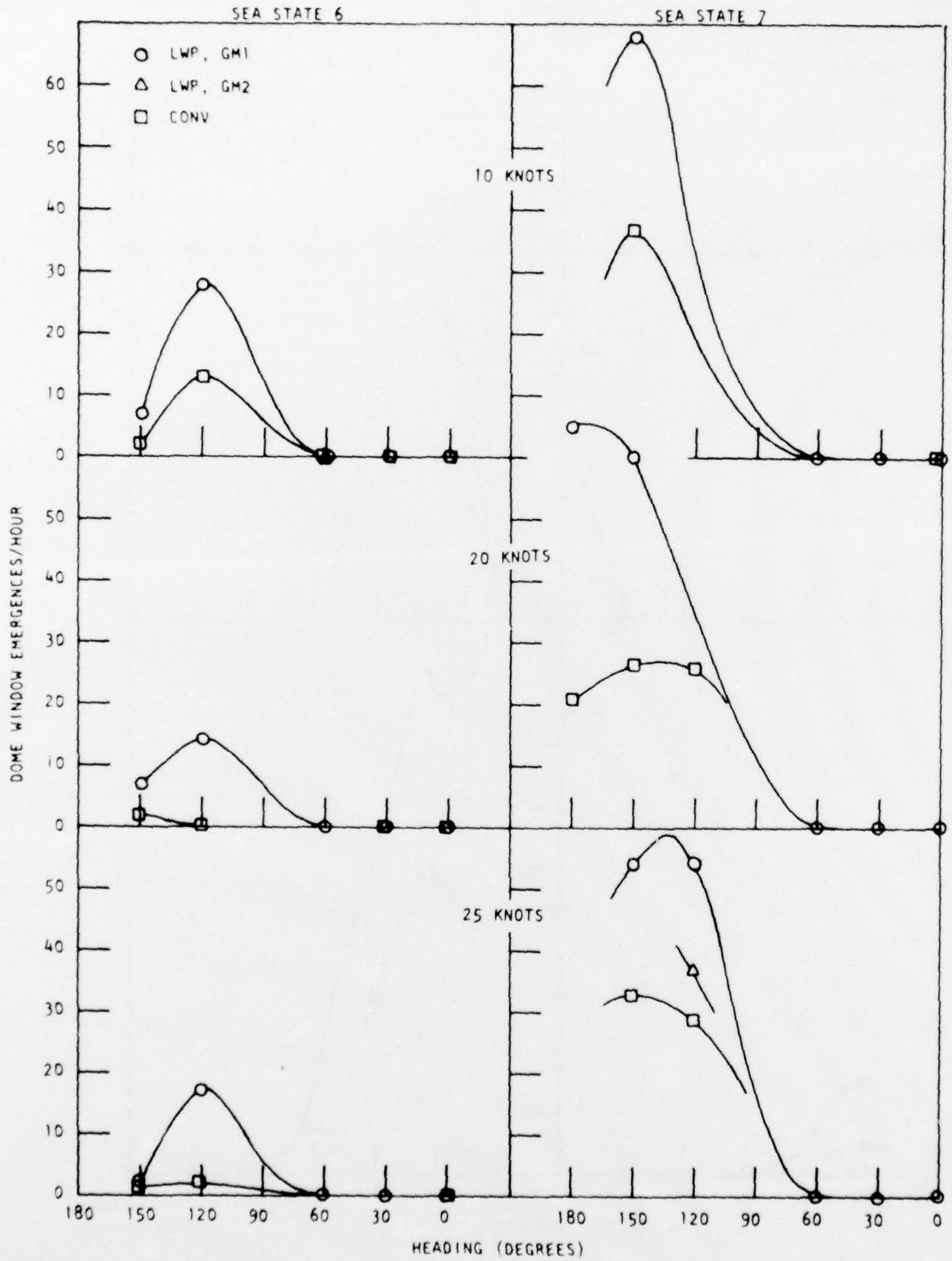

Figure 8 - Sonar Dome Window Emergence Rate versus Relative Wave Heading

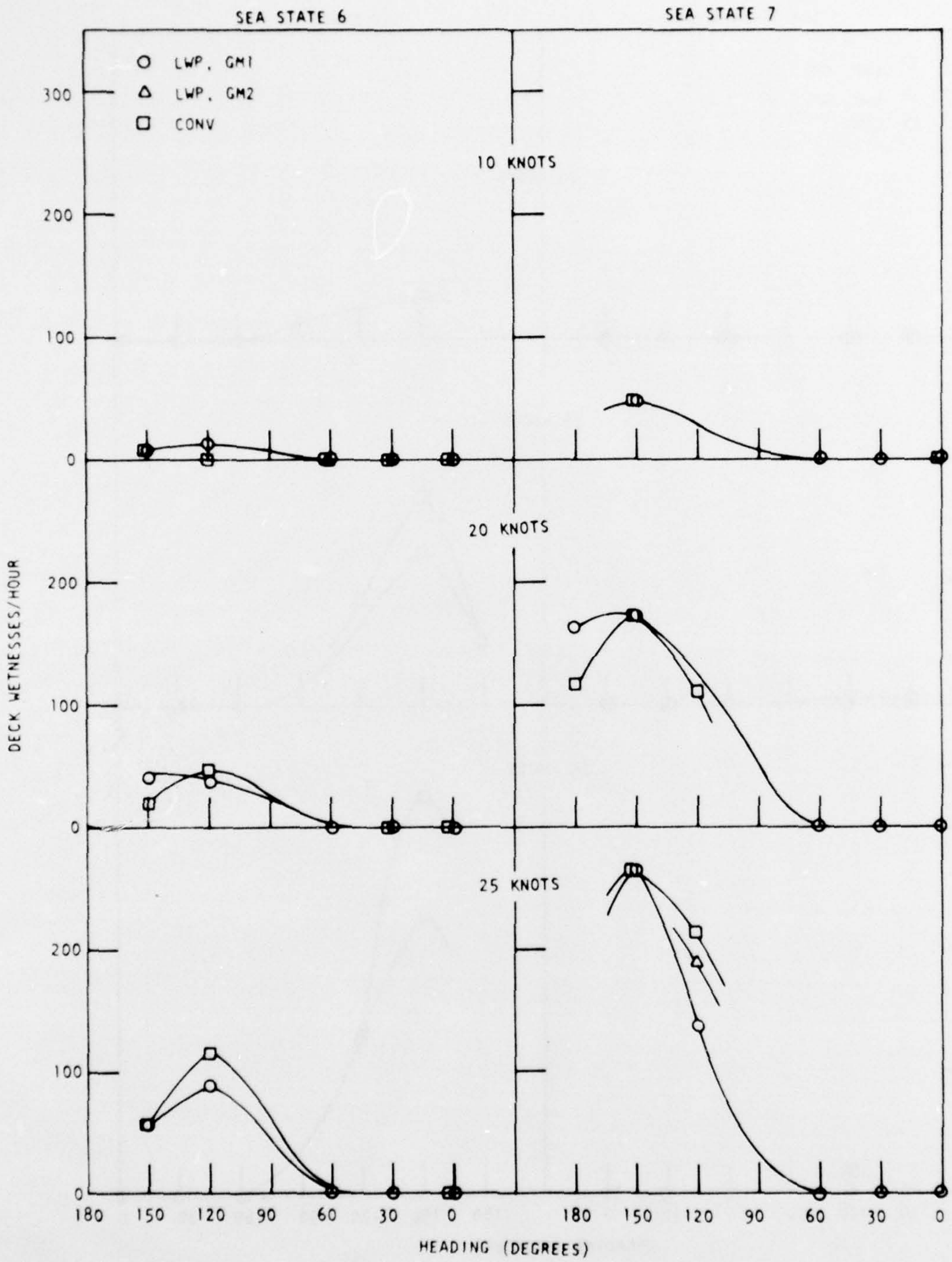

Figure 9 - Bow Deck Wetness Rate versus Relative Wave Heading

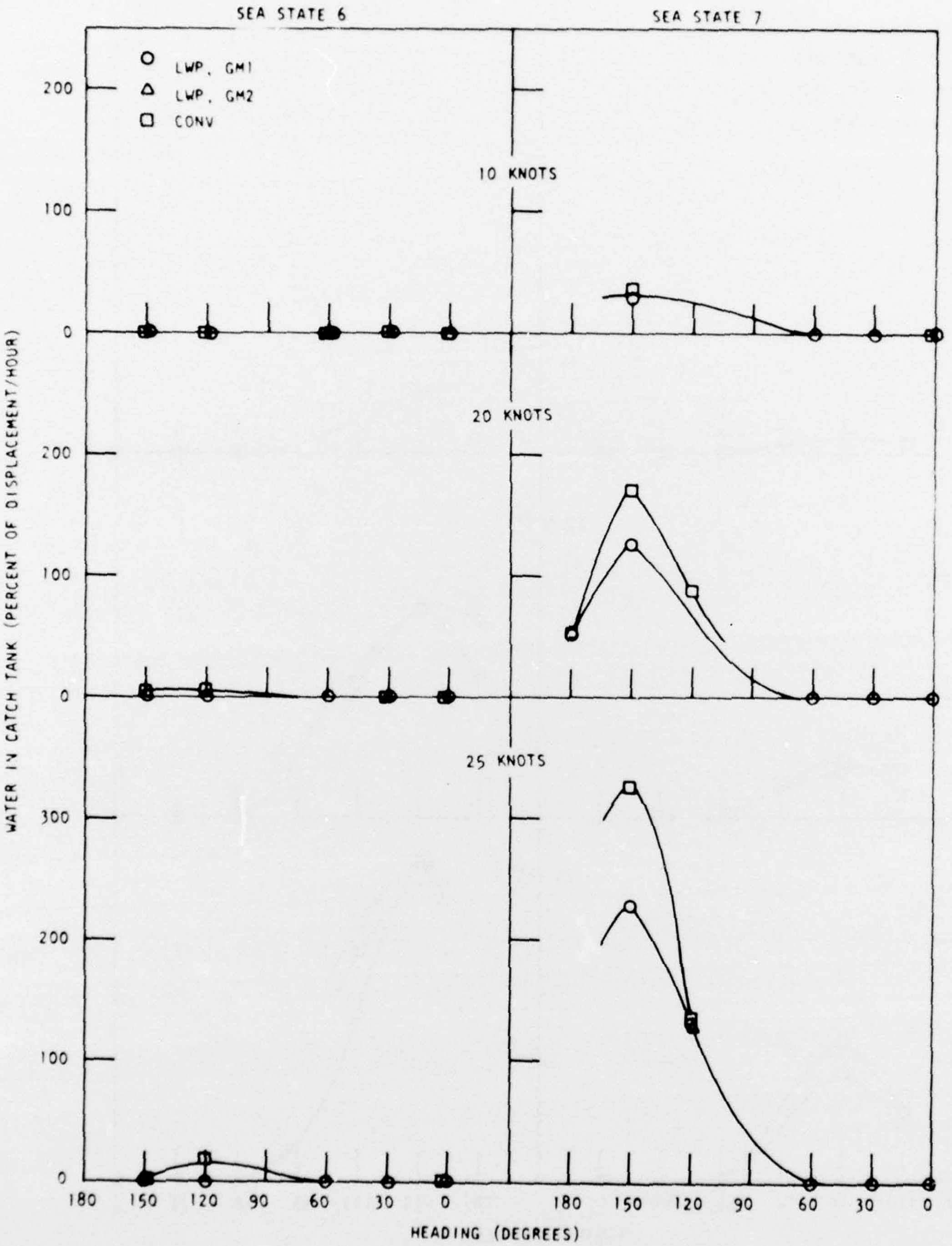

Figure 10 - Water in the Catch Tank Rate versus Relative Wave Heading

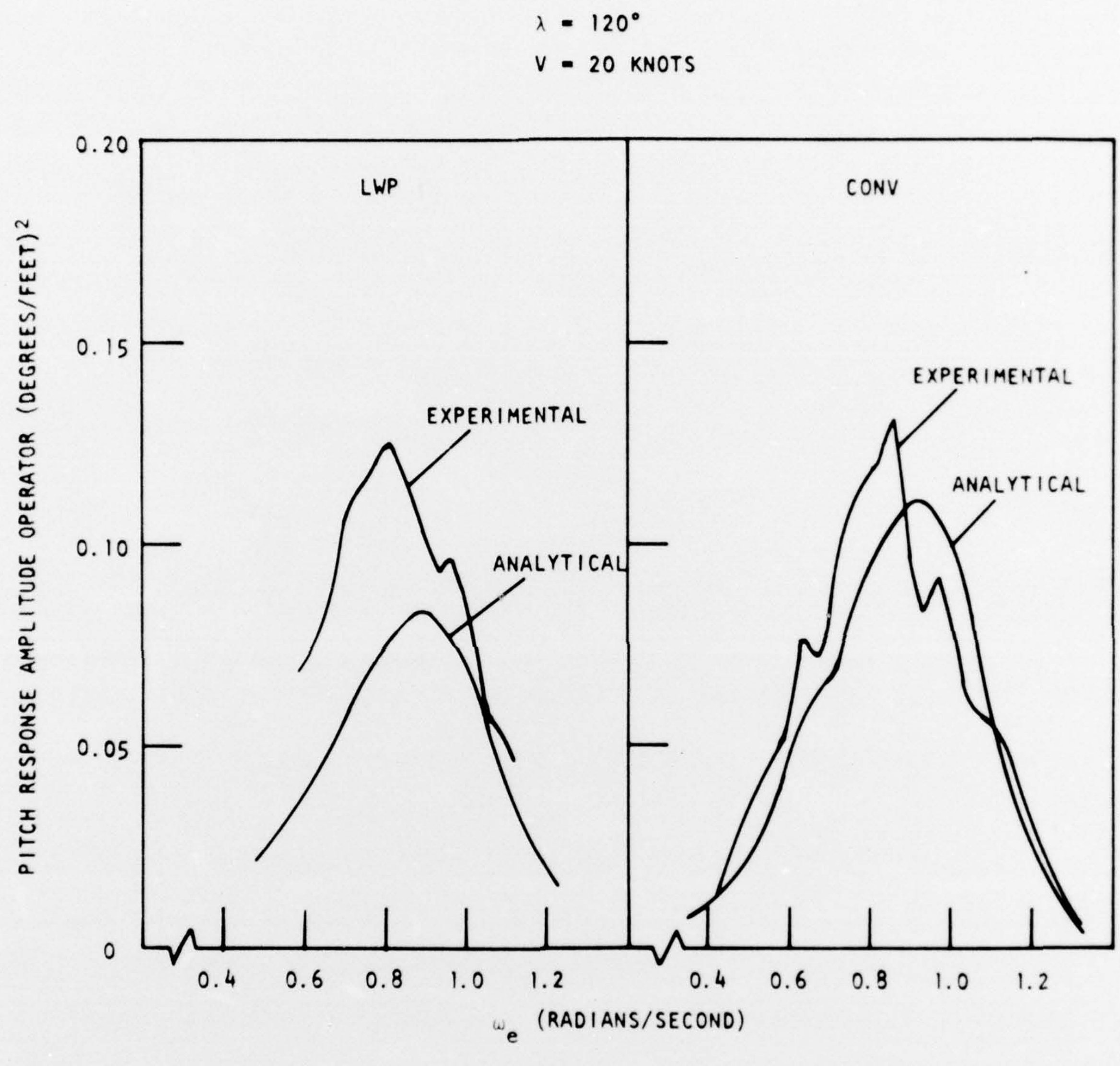

Figure 11 - Comparison of Experimental and Analytical Pitch Response Amplitude Operators as a Function of the Frequency of Encounter

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